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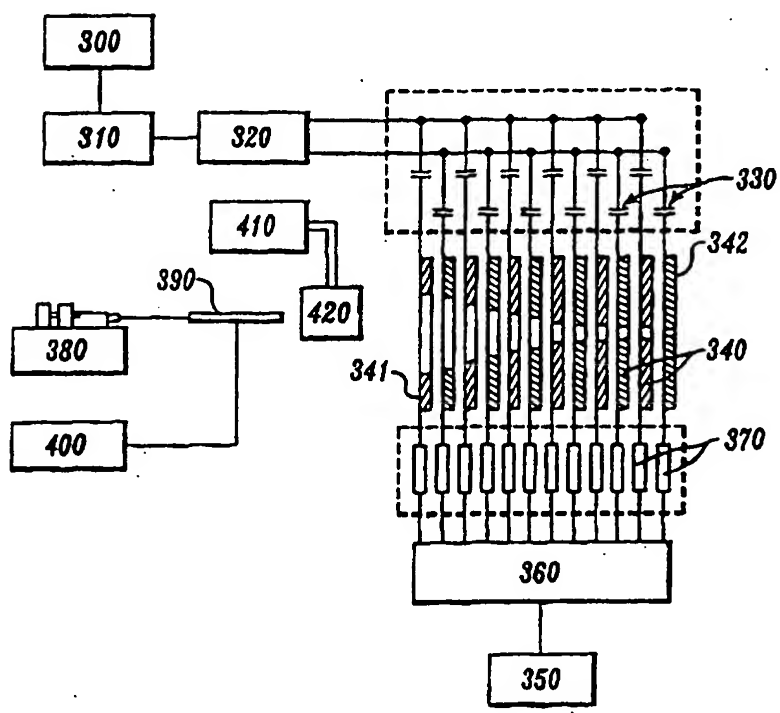
(54) Title: METHOD AND APPARATUS FOR ION AND CHARGED PARTICLE FOCUSING

(57) Abstract

A method and apparatus for focusing dispersed charged particles. More specifically, a series of elements, each having successively larger apertures forming an ion funnel, wherein RF voltages are applied to the elements so that the RF voltage on any element has phase, amplitude and frequency necessary to define a confinement zone for charged particles of appropriate charge and mass in the interior of the ion funnel, wherein the confinement zone has an acceptance region and an emmitance region and where the acceptance region area is larger than the emmitance region area.



METHOD AND APPARATUS FOR ION AND CHARGED PARTICLE FOCUSING

FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for focusing dispersed charged particles in the presence of a gas. The invention allows a dispersion of charged particles to be effectively focused.

BACKGROUND OF THE INVENTION

There is a broad need to collect, focus and analyze charged particles. The need spans all charged particles including subatomic particles, small ions, and charged particles and droplets exceeding a micron in diameter. For example, many analytical or industrial processes require the generation of beams of charged particles of particular substances or analytes. In some cases the ion current is measured, generally as a function of time, as in ion mobility analysis or with thermal, flame or photoionization detectors used in conjunction with gas chromatography separations. Also, charged particles beams are used in ion guns, ion implanters, laser ablation plumes, and various mass spectrometers (MS), including quadrupole MS, time of flight MS, ion trap MS, ion cyclotron resonance MS, and magnetic sector MS. In mass spectrometry applications, typical arrangements often combine the charged particles or analyte with a carrier gas in an electrical field, whereupon particles are ionized by one method or another (e.g., inductive charging of particles) for use in an analytical process. Increasingly, ion sources for MS and other applications

operate at higher pressure, where the presence of a gas or air is either essential to the ionization process or is an unavoidable consequence of the process.

Several schemes are known in the art for generating charged particle beams including electrically and mechanically assisted spray ionization techniques, electrospray, thermospray, chemical ionization, inductively coupled plasma sources, glow discharges and hollow cathode discharges, and many variations on these methods.

Uses for charged particle beams and the need for the manipulation of charged particles extends well beyond mass spectrometry, and include particle analysis and collection, materials synthesis, atmospheric monitoring, and other applications where charged particles exist or are produced.

The use of DC electrical (electrostatic) fields, generated by a variety of methods, for the manipulation of charged particles or to assist in the collection of charged particles, is well known in the art. In ion sources operated at higher pressures, an unavoidable consequence is the presence of gas phase collisions and charge-charge repulsion interactions that lead to expansion of the ion cloud. Conventional ion optics devices such as electrostatic devices which can function effectively to focus ions under vacuum conditions are ineffective for avoiding or reversing the ion cloud expansion brought about by gas phase collisions and the repulsive electrical forces between charged particles.

In many applications, the dispersion of the charged particle beam or ion cloud is undesirable. For example, it is often desirable that the charged particle beam be

focused through a small aperture, or there may be a desire to direct an ion beam having a particular shape through an aperture having a different shape. For example, if a charged particle beam is to be directed through an aperture having a square shape, it would be useful to have a means of changing the shape of the charged particle beam to one having a square shape. In this manner, the shape of the charged particle beam could be matched to the desired use. If the charged particles of analyte are to be analyzed using a mass spectrometer, it is often typical that a charged particle or ion beam be generated at a higher pressure, for example, approximately atmospheric pressure in the case of electrospray ionization, and must pass to a region maintained at a much lower pressure where the mass spectrometer can function effectively. In such an arrangement, the charged particle beam is directed through at least one small aperture, typically less than 1 mm diameter, which are used to maintain the pressure differential. Several stages of differential pumping are often used to accomplish the pressure differences, and thus each region would have an aperture in order to limit gas flow into the lower pressure region. Because of the dispersion of the charged particle beam, and the limited cross section defined by the aperture, a significant portion of the beam is typically unable to pass through the aperture and is thus lost. In many applications, a portion of the beam which is lost includes ions of interest, and may thus result in a decrease in the sensitivity of the analytical device. This can serve to preclude many analytical applications. Also, a loss of a portion of the beam may result in a disproportionate loss

of the ions of analyte because the ions of analyte may not be evenly distributed throughout the charged particle beam.

In other uses of charged particles, it may be desirable to direct or collect dispersed charged particles which have not been generated as part of an charged particle beam per se. For example, in an atmospheric charged particle sampling device, it may be desirable to sample a large volume of air for the presence of some charged particles of interest. These charged particles may be ambient, or produced by photoionization or other means. It would be useful to have a means by which charged particles in the air are captured and directed to a detector, collector or other devices. Examples of possible uses include environmental monitoring for releases of ambient ions, aerosols, and other ion-producing processes such as combustion.

Many devices have been designed for focusing ion beams. Many such devices are based upon the use of constant DC (electrostatic) fields. Also, time varying (electrodynamic) or radiofrequency (RF) electric fields can be applied for focusing purposes. An example of such RF devices are RF multipole devices in which an even number of rods or "poles" are evenly spaced about a line that defines the central axis of the multipole device. These include quadrupole, hexapole, octopole and "n-pole" or greater multipole devices that are used for the confinement of charged particles in which the phase of the RF is varied between adjacent poles. The use of these devices can result in focusing of an ion beam due to collisional damping in the presence of a gas as described in U.S. Patent 4,963,736 to D.J. Douglas

entitled "Mass Spectrometer and Method with Improved Ion Transmission" and U.S. Patent 5,179,278 to D.J. Douglas entitled "Multipole Inlet System for Ion Traps." It is generally recognized that RF multipole devices can be used to trap or confine charged particles when operated at appropriate RF frequencies and amplitudes. In such arrangements, the motion of charged particles of appropriate mass and charge is constrained by the effective repulsion (of the "pseudo potential") arising from the RF field near the electrodes (poles). The charged particles thus tend to be repulsed from the region near the electrodes and tend to be confined to the inner region which is relatively field free. Thus, for example, in quadrupole devices, which are typically operated in high vacuum, ions tend to oscillate about the center of the area inscribed by the four poles. In multipole devices with larger numbers of poles, the increased number of poles enlarges the region of lower field, or region which is effectively field free. Also known in the art are ring electrode devices wherein the field free region is dictated by the diameter of the ring. Ring electrode devices consist of conductive rings having an equal spacing between rings, and have confinement properties determined by the diameter of and the ring thickness which roughly corresponds to the properties determined by the rod diameter and spacing in multipole devices. The similar alternating phase of the RF voltages for each subsequent ring of such devices enables their use as "ion guides." Such devices are used far less frequently than conventional multipole ion guides.

Also known in the art are quadrupole mass filters which use DC potentials with quadrupole devices to discriminate ions according to their mass to charge ratio.

In the presence of a low pressure gas, these types of ion guides do result in a reduction of the dispersion of the ions due to collisional damping of charged particles to the field free region. At higher pressures however, ion velocities may become too small for ions to rapidly exit the multipole, resulting in a build up of space charge and decreased ion transmission.

The nearly field free region is constant across the length of the multipole or ring electrode device and includes some fraction of the volume inscribed by the poles or rings. Given a fixed number of poles or rings, the nearly field free region may thus only be significantly increased by increasing the distance between the poles or rings and the diameter of the poles or rings, both of which require an increase in the RF voltage applied to the poles or rings to obtain effective confinement. Again, given a fixed number of poles or rings, the size of a cross section of the field free region, and thus the size of the region which accepts ions (or the ion acceptance region), increases as the square root of the RF voltage applied to the poles or rings. Thus, to create any significant gain in the cross section of the field free region, and thus the ion acceptance region, requires prohibitively large RF voltages. Larger acceptance regions can also be obtained by the use of higher multipole devices, but a general failing of this approach is that the nearly field free region becomes correspondingly large and effective

focusing to a small region is not obtained. Thus, there exists a need for a device with an acceptance region which is larger than the emission region which can both guide ions and focus a dispersion of charged particles.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention in one of its aspects to provide a method for reducing the dispersion of charged particles. This is accomplished by providing an apparatus, hereinafter referred to as an "ion funnel", which generates an RF field having a field free zone with an acceptance region and an emmitance region, where the acceptance region is larger than the emmitance region. The ion funnel has at least two members, each member having an aperture, such that the apertures are disposed about a central axis and define a region of charged particle confinement. The members, by way of example, can be formed as circular rings, wherein the interior diameter of the ring defines the aperture. Some fraction of this interior diameter defines the useful acceptance region of the device. However, the members and the apertures are not limited to circular forms and may take any shape. The first aperture, or entry, of the ion funnel is larger than the second aperture, or exit. A funnel shape is thus created by the boundaries of the apertures, which also defines the side or sides of the ion funnel. The size and shape of the entry and exit apertures, as well as apertures disposed between the entry and the exit, are selected to control the size and shape of a beam or cloud of charged particles (such as ions) directed through the ion funnel.

A cross section of the funnel may be any shape, for example, round, square, triangular or irregularly shaped, and the shape of the cross section may vary along the length of the ion funnel. Thus, examples of desired shapes for the apertures of the ion funnel would thus include, but not be limited to, circular, oval, square, trapezoidal, and triangular.

The ion funnel has RF voltages applied to alternating elements such that progressing down the ion funnel, the RF voltages alternate at least once, and preferably several times, so that the RF voltages of adjoining elements are out of phase with adjacent elements. In general, adjacent elements may be out of phase with one and another by between 90 degrees and 270 degrees, and are preferably 180 degrees out of phase with one and another. Thus, an RF field is created with a field free zone in the interior of the ion funnel wherein the field free zone has an acceptance region at the entry of the ion funnel and an emmitance region at the exit of the funnel and the acceptance region is larger than the emmitance region. The RF voltages thus act to constrain charged particles within the field free region, and as charged particles move from the entry to the exit, the field free region decreases in diameter to confine the charged particles into a smaller cross section. Charged particles driven through the ion funnel are thus focused into a charge particle beam at the exit of the ion funnel. Ions so effected can be said to be "trapped" or "directed" by the ion funnel. Also, by varying the shape of the apertures, the shape of the resultant charged particle beam may be varied to correspond to a shape desired by the user.

It is a further object of the invention in one of its aspects to provide a method for driving charged particles through the ion funnel. This may be accomplished by providing a DC potential gradient across the adjacent elements of the ion funnel in addition to the RF voltages applied to the elements. For example, a resistor chain may be used to effect a gradual change in the DC electric field across the individual elements. Each element thus has a time varying voltage corresponding to the summation of the applied DC and RF potentials. The simultaneous constraining force supplied by the RF currents and driving force supplied by the DC gradient thus acts to drive charged particles through the ion funnel.

Alternatively, or in combination with the DC field, mechanical means may be employed for driving the charged particles through the funnel. For example, methods based on gas dynamics may be applied. In this case a gas flow pressure gradient or partial vacuum at the exit of the ion funnel may be employed to push or draw charged particles through the funnel. Also, a fan may also be employed to blow charged particles into the entry and through the funnel.

The specific configuration of the ion funnel may be easily altered to suit a desired need. For example, in applications for atmospheric monitoring for ambient charged particles, the entry may be made as large as desired, since the frequency and RF voltages necessary for effective operation depend primarily upon the elements thickness and the spacing of the elements, but not the acceptance area. Also, the ion funnel may be configured to trap or direct particles with specific mass to charge (m/z) ratios. For example, all else held

constant, thinner elements would trap or direct higher m/z ions or charged particles while thicker elements would trap lower m/z ions or charged particles. Similarly, all else held constant, the use of higher RF frequencies would tend to trap or direct charged particles or ions having smaller m/z ratios. Likewise, all else held constant, the use of larger voltages would tend to trap or direct charged particles or ions having larger m/z ratios. Finally, as described above, the shape of the cross section of the resultant charged particle beam may be controlled by changing the shape of the elements or the apertures in the elements.

It should be noted that the ion funnel herein described may be utilized in a wide variety of settings where it is desired to focus a dispersion of charged particles. For example, the ion funnel utilized in mass spectrometers, such as for combined on-line capillary electrophoresis mass spectrometry, would allow much improved focusing of the ion current and thus greatly enhanced analytical sensitivity. In a typical mass spectrometer, the ion current is directed through a series of chambers which are subjected to pumping to reduce pressure to a level amenable with mass spectromic analysis. The chambers are thus separated by apertures designed to limit gas flow and allow a transition form a region at higher pressure to a region at lower pressure. By positioning the ion funnel or a series of ion funnels at the apertures in these chambers, the ion beam may be effectively focused form chamber to chamber. Thus, several ion funnels may be used in a sequence to guide an ion beam through each of the chambers. Another use of the ion funnel would be the introduction of ions through

the ion funnel into an ion mobility analyzer. By focusing the ions, the ion funnel would increase the ion current and prevent ion loss due to ion cloud expansion in the ion mobility analyzer during the drift period thereby improving the resolution, dynamic range, and sensitivity of the ion mobility analyzer. Similarly, in applications where diffuse ion beams are generated by methods such as electrospray, thermospray, and discharge ionization, the ion funnel allows greater ion current, and due to the focusing effect on the ions and resultant decrease in ion dispersion, greater ability to aim or focus the ion beam at a desired target, collection device or detector. Used in conjunction with photo-ionization sources, much greater ion collection efficiency and sensitivity can be obtained since the ionization volume can be made arbitrarily large. Also, the ion funnel may be used to trap charged particles by applying a DC potential to the exit of the ion funnel sufficient to preclude the escape of the charged particles of interest. The ion population could therefore be increased in the ion funnel "trap" to a high level, and the DC potential could be lowered at any time to release the trapped ions in a pulse for introduction to another region. Coordinating the release of the pulse of ions with the opening of mechanical shutter or gate used to block a aperture separating two regions maintained at different pressures by differential pumping, thus allowing significant advantages. For example, because it is only necessary to open the gate or shutter at the precise moment of the release of the trapped ions, a great reduction in the gas load on the pumping system can be achieved. This allows high sensitivity for instruments

using only small vacuum pumps. The foregoing is only a single example of a possible use of the ion funnel's capability to trap ions and release ions in a pulsed fashion. Other uses and advantages of trapping ions and releasing ions in a pulsed fashion will be apparent to those skilled in the art, and the use of the present invention should in no way be limited to the example of releasing ions in a pulsed fashion in conjunction with a shutter or gate used to block an aperture separating two regions maintained at different pressures by differential pumping.

The ion funnel also allows the capture of free ions in gaseous atmospheres where no particular ion source is apparent. For example, by forcing air through an ion funnel, ions of interest may be effectively directed towards a detector for atmospheric analysis. As demonstrated by the foregoing, and as will be apparent to those skilled in the art, the ion funnel is useful across a broad range of activities and in a broad range of devices where it is desirable to focus dispersed ions. The present invention should in no way be limited to its incorporation in any particular application, device or embodiment.

When charged particles are driven into the entry and then through the plurality of apertures which make up the ion funnel, the effect of the combined forces and fields is to direct the charged particles through the exit of the ion funnel. In this manner, a dispersion of charged particles is compressed as they pass through the ion funnel, and the charged particles are focused from a dispersion into a compact beam. The charged particles may be driven by either mechanical means, for example a

fan, a vacuum, or both, or electrical means, for example by providing a dc potential gradient down the central axis of the ion funnel by providing increasing DC voltages to each of the elements. The final aperture can also be used to define the passage into a region of lower pressure, as in a mass spectrometer vacuum system incorporating multiple regions of differential pumping. Alternatively, the final element may be positioned immediately adjacent to such an aperture. In either case concerns about focusing, space charge, differential pumping, and possible electrical discharges, familiar art to those who work in this field, must be considered in the design of any specific implementation. It must also be recognized that it is possible to use multiple ion funnels in series. One case where this is particularly attractive is in regions of different pressure so that ions can be effective transferred through multiple aperture with minimal losses. It should also be recognized that the optimum RF and DC electric fields may be significantly different for such multiple funnel devices; one reason for this would be differences in pressure that would alter the effect of the gas collisions.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description taken in connection with accompanying drawings wherein like reference characters refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross section of a first preferred embodiment the present invention.

Fig. 2 is an isometric view of a second preferred embodiment the present invention.

Fig. 3 is schematic drawing of a prototype of the present invention.

Fig. 4 is a graph of the measured ion current in nanoampres at atmospheric pressure as a function of the applied RF in kV in the apparatus of the second prototype.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

In a first preferred embodiment of the present invention, as illustrated in **FIG. 1**, a plurality of elements or rings **10** are provided, each element having an aperture, defined by the ring inner surface **20**. At some location in the series of elements, each adjacent aperture has a smaller diameter than the previous aperture, the aggregate of the apertures thus forming a "funnel" shape, or an ion funnel. The ion funnel thus has an entry, corresponding with the largest aperture **21**, and an exit, corresponding with the smallest aperture **22**. The elements **10** containing the apertures **20** may be formed of any sufficiently conducting material, preferably, the apertures are formed as a series of conducting rings, each ring having an aperture smaller than the aperture of the previous ring. An RF voltage is applied to each of the successive elements so that the RF voltages of each successive element is 180 degrees out of phase with the adjacent element(s), although other relationships for the

applied RF field would likely be appropriate. Under this embodiment, a DC electrical field is created using a power supply and a resistor chain to supply the desired and sufficient voltage to each element to create the desired net motion of ions down the funnel.

In a second preferred embodiment, as illustrated in **FIG. 2**, the ion funnel may be formed of two conducting conical coils **100** which are fashioned to lie in a helix with one beside the other. The illustration of **FIG. 2** is drawn to illustrate the relative positions of conical coils **100**; in a preferred embodiment the spacing **S** between the conical coils is approximately equal to the thickness **T** of the individual coils. The widest end of the coils form the entry of the ion funnel, and the narrow end of the coils forms the exit of the ion funnel. Such an arrangement allows the alternating successive rings to be substituted with the two element coils, while still allowing each coil element to alternate RF phase with the adjacent coil element. Wide variations in geometry or shape of the device are feasible, the important feature being the difference in RF phase for the adjacent elements that serves to create a confinement. A DC field to drive charged particles through the device may be created by the use of resistive materials, thus creating an actual DC voltage drop across the length of each element. Alternatively, as in the first preferred embodiment, the DC field may be eliminated or used in combination with a driving force created by mechanical means (e.g., hydrodynamics associated with gas flow). In this manner, dispersed charged particles may be propelled through the device to

achieve the desired reshaping or compression of the charged particle distribution.

Example 1

A prototype ion funnel was built to demonstrate the principle of the invention. In this prototype, four triangles were cut from nonconducting circuit board material and placed edge to edge to form a four sided pyramid with a square aperture forming the base, or entry. The pyramid was 2 1/2" across at the base, or entry, and had a 1/8" aperture at the top, or exit. Approximately 100 conductive copper strips 0.5 mm in diameter were formed into a series of squares with decreasing size and adhered to the interior walls of the pyramid to form the ion funnel. RF voltages were applied to each of the copper strips such that the RF voltage on each strip was 180 degrees out of phase with the RF voltage applied to the adjoining strip(s). A driving force was generated by applying an increasing DC voltage to each of the successive strips. The largest strip at the base or entry was given a DC potential of about 900 volts and each successive strip was given a voltage of 8.5 V less so that the smallest strip at the top or exit was given a DC potential of about 50 volts. Charged particles generated at atmospheric pressure by a corona discharge were then directed at the entry of the ion funnel. A pico ammeter was then used to detect charged particles at the exit. The first prototype was tested at RF frequencies between about 100 kHz and 1 MHz. Currents ranging from 0 to about 2 nAmp were detected indicating the flow of charged particles through the ion funnel with

an efficiency depending upon the RF amplitude and DC potential.

Example 2

As illustrated in **Fig. 3**, a second prototype ion funnel was built. A series of 12 stainless steel elements each 1/16" in thickness were placed parallel to one and another to form a second prototype ion funnel. Circular apertures of increasing diameters, ranging from about 1 mm at the exit of the ion funnel to about 25mm at the entry of the ion funnel, had been cut in the elements. As shown in **FIG. 3**, an RF voltage was first generated in a signal generator **300** and then amplified with an amplifier **310**. The amplified signal was then matched and balanced with a RF High Q Head **320**. A series of capacitors **330** were then used to apply the RF signal applied to each of the elements **340** which were 180 degrees out of phase with the RF signal applied to adjacent elements. Simultaneously, a DC voltage supply **350** provided a DC voltage to a voltage divider **360** which then fed the voltage to a series of resistors **370**, which in turn fed the voltage to the elements **340**. In this manner, DC voltage was varied across the elements with a DC voltage of about 500 to 800 V at the element **341** at the entry of the funnel and a DC voltage of about 100 to 200 V at the element **342** at the exit of the funnel. A syringe pump **380** feeding a solution of cytochrome from a capillary **390** charged with a DC high voltage supply **400** was utilized to provide an ion stream from an electrospraying of the solution as would generally be necessary to form small ions from the charged droplets initially created by the electrospray. A heating power

supply **410** also fed a heating mechanism **420** to heat the capillary. In this manner, droplets produced at the capillary tip having a very high mass to charge ratio were evaporated or dissociated into charged particles having smaller mass to charge ratios. The heating step tends to increase the expansion of the resultant ion cloud volume, but the smaller mass to charge particles that result were more effectively directed by the fields generated in the ion funnel. Again, the resultant ion current was measured at the ion funnel exit using a picoammeter.

FIG. 4 shows the measured ion current in nanoampres at atmospheric pressure as a function of the applied RF in kV in the apparatus of the second prototype. The discharge capillary was charged at about 3.09 kV, and the DC voltage was varied across the elements from about 100 V to about 500 V, as indicated in **Fig. 4**. The RF frequency was applied at about 950 kHz. By comparing the measured ion current at 0 RF amplitude, and at the greatest RF amplitude, it can be seen that the second prototype of the ion funnel thus produced an ion current measured at about 100 times the ion current produced without the ion funnel.

While a preferred embodiment of the present invention has been shown and described, it will be apparent to those skilled in the art that many variations, changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

CLAIMS

We claim:

1. A method of focusing dispersed charged particles comprising the steps of:

a) providing a plurality of elements, each of said elements having successively larger apertures wherein said apertures form an ion funnel having an entry at the largest aperture and an exit at the smallest aperture,

b) applying an RF voltage to each of the elements wherein the RF voltage applied to each element is out of phase with the RF voltage applied to the adjacent element(s),

c) directing charged particles into the entry and out of the exit of the ion funnel, thereby focusing the charged particles.

2. The method of **Claim 1** further comprising the step of directing the charged particles is provided by a mechanical means.

3. The method of **Claim 2** wherein the mechanical means is selected from the group comprising a fan and a vacuum, or combinations thereof.

4. The method of **Claim 1** further comprising the step of directing the charged particles by providing a DC potential gradient across the plurality of elements.

5. The method of **Claim 1** further comprising the step of directing the charged particles into the ion funnel at about atmospheric pressure.

6. The method of **Claim 1** further comprising the step of providing a plurality of said ion funnels in series.

7. The method of **Claim 1** wherein the entry of said ion funnel is provided in a region of space maintained at a pressure higher than the exit of said ion funnel.

8. An apparatus for focusing dispersed charged particles comprising:

a) a plurality of elements, each of said elements having progressively larger apertures wherein said apertures form an ion funnel having an entry at the largest aperture and an exit at the smallest aperture and an RF voltage applied to each of the elements wherein the RF voltage applied to each element is out of phase with the RF voltage applied to the adjacent element(s).

9. The apparatus of **Claim 8** further comprising a mechanical means for directing charged particles through the ion funnel.

10. The apparatus of **Claim 9** wherein the mechanical means is selected from the group comprising a fan and a vacuum, or combinations thereof.

11. The apparatus of **Claim 8** further comprising a DC potential gradient across the plurality of elements.

12. The apparatus of **Claim 8** wherein the shape of said apertures are selected from the group comprising circular, oval, square, trapezoidal, and triangular.

13. The apparatus of **Claim 8** wherein ion funnel is incorporated to focus a dispersion of charged particles in a mass spectrometer.

14. The apparatus of **Claim 8** wherein ion funnel is incorporated to focus a dispersion of charged particles in
an ion mobility analyzer.

15. A method of trapping charged particles comprising the steps of:

a) providing a plurality of elements, each of said elements having successively larger apertures wherein said apertures form an ion funnel having an entry at the largest aperture and an exit at the smallest aperture,

b) applying an RF voltage to each of the elements wherein the RF voltage applied to each element is out of phase with the RF voltage applied to the adjacent element(s),

c) providing a DC voltage at the exit of said ion funnel sufficient to capture said charged particles, and

d) directing a volume of gas containing said charged particles into the entry of said ion funnel, thereby capturing said charged particles in said ion funnel.

16. The method of **Claim 15** further comprising the step of reducing the DC voltage applied to the exit of said ion funnel, thereby releasing said charged particles captured in said ion funnel.

17. The method of **Claim 17** further comprising the steps of:

a) providing said ion funnel at an aperture separating two regions maintained at different pressures, said aperture being covered by a gate,

b) reducing the DC voltage applied to the exit of said ion funnel while simultaneously opening said gate, thereby releasing said charged particles captured in said ion funnel and directing said ions through said aperture.

18. The method of **Claim 15** wherein said volume of gas is drawn from the atmosphere and said charged particles are ambient ions found in the atmosphere.

19. An apparatus for focusing dispersed charged particles comprising:

a) two elements placed adjacent to each other, each of said elements formed into a conical coil, said coils forming an ion funnel having an entry at the largest end and an exit at the smallest end, wherein an RF voltage is applied to each of the elements and said RF voltage applied to each element is 180 degrees out of phase with the RF voltage applied to the adjacent element.

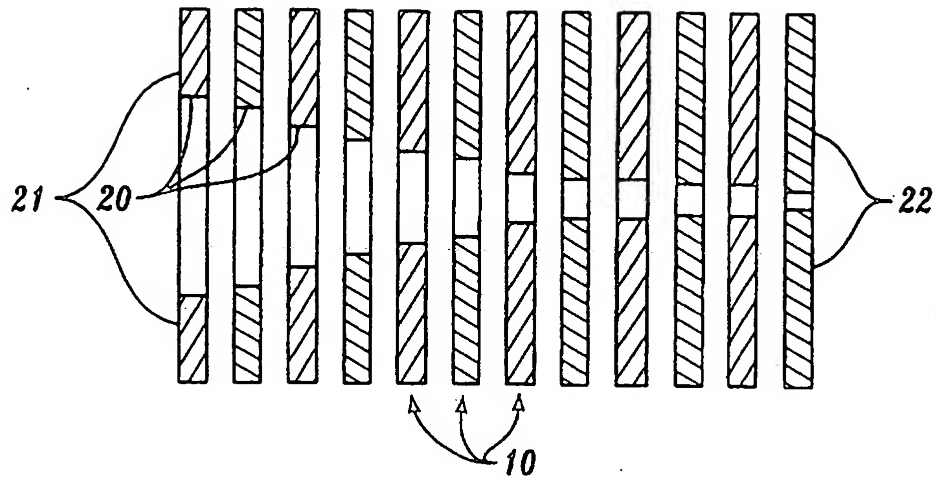


Fig. 1

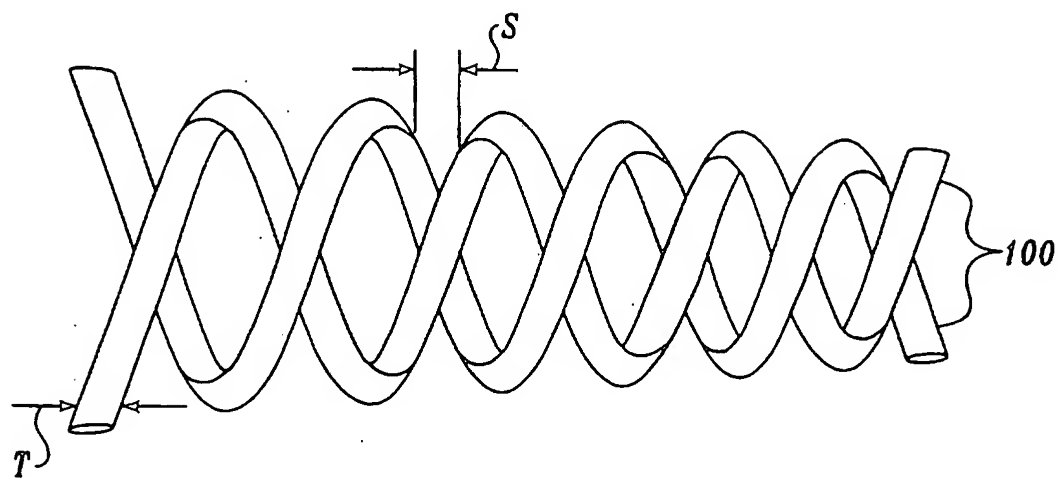


Fig. 2

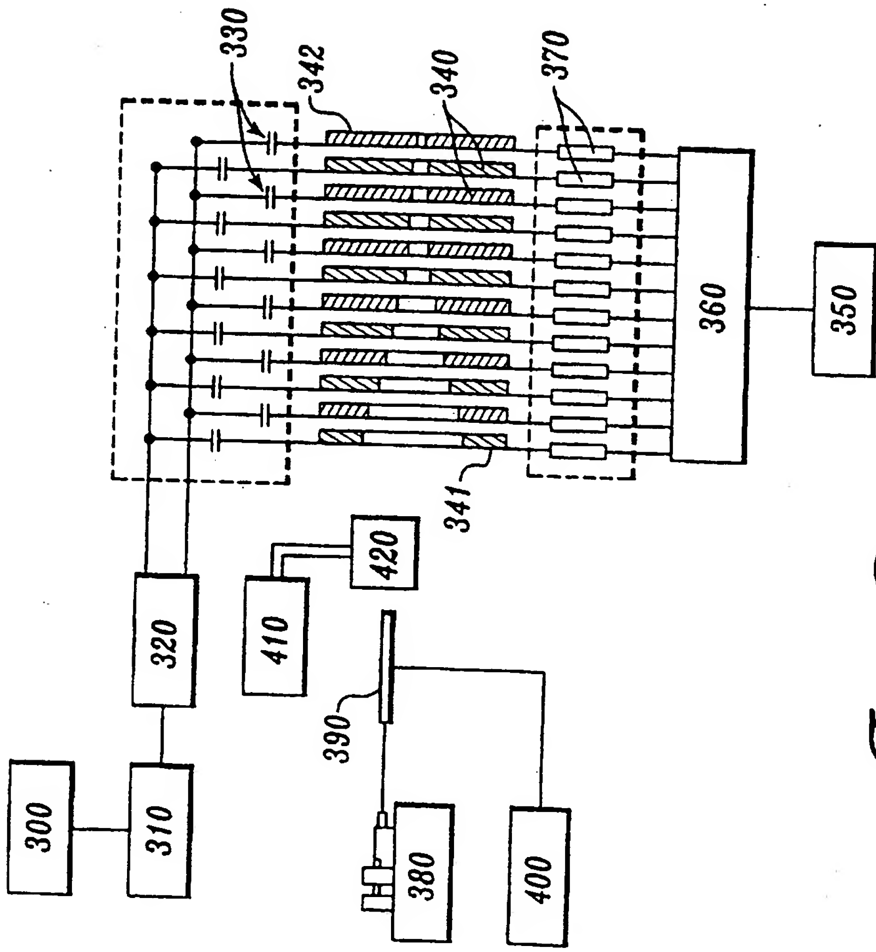


Fig. 3

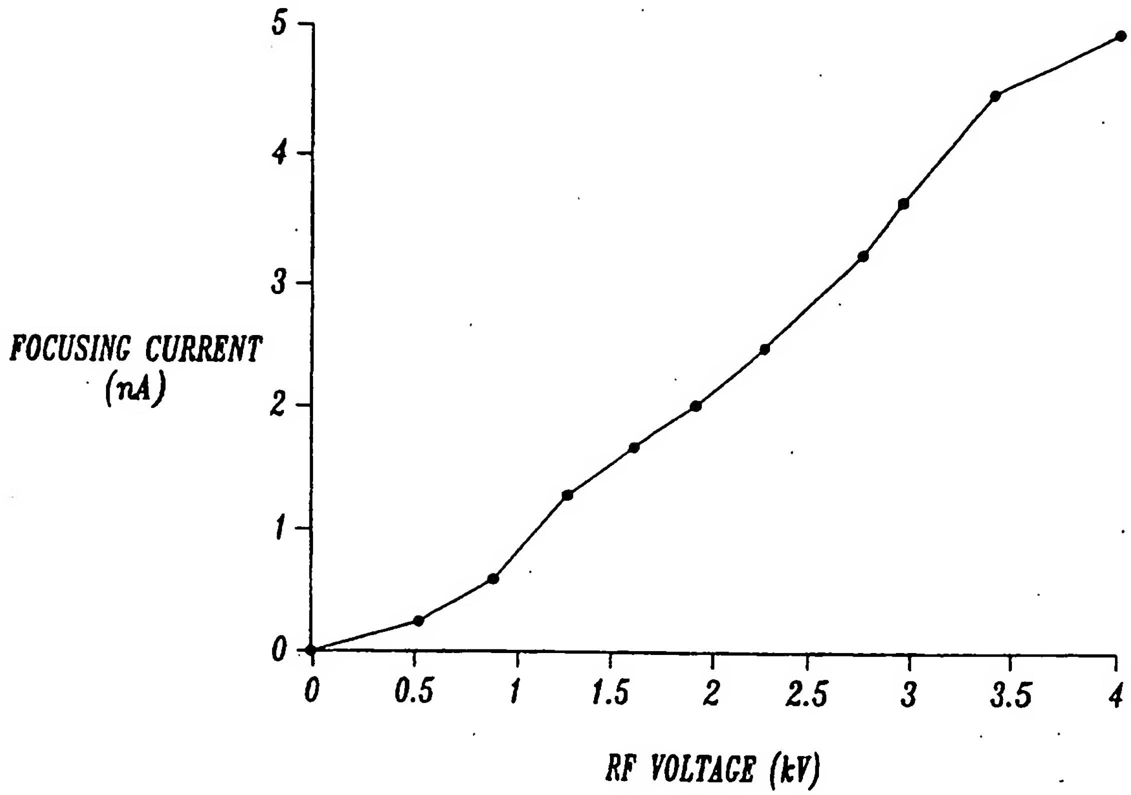


Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/09315

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 H01J29/46 H01J29/48 H01J29/56 H01J29/58 H01J29/62 H01J37/04 H01J37/063 H01J37/08 H01J37/12 H01J37/147 H01J37/21 H01J37/26 H01J37/30 H01J29/80

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 683 194 A (LEVIN NATHAN D ET AL) 8 August 1972 see column 2, line 35 - column 3, line 5; figure 1	1-18
A	JP 07 226 171 A (KINSEISHA K.K. / GOLDSTAR CO. LTD.) 22 August 1995 see the whole document	1-18
A	US 5 397 959 A (TAKAHASHI CHIE ET AL) 14 March 1995 see the whole document	1-18
A	EP 0 369 101 A (SAM SUNG ELECTRONIC DEVICES) 23 May 1990 see the whole document	1-18

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 October 1997	19. 11. 97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bergado Colina, J

Interr. nal Application No
PCT/US 97/09315

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A	EP 0 513 909 A (PHILIPS NV) 19 November 1992 see the whole document -----	19

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